a Schmidt optical system of extremely low mass which focuses the Sun's rays on the hot junctions of a thermopile while the cold junction is kept at 380° by means of an evaporative cooling system with a large condenser. Considering the Solar constant at the Earth's orbit to be about 1.5 kW/sq. meter, it is concluded that such a system, having a maximum radius of 425 meters, could generate 10,000 kW of electrical energy and that it would be built for as little as 120 grams/kW. Figures 7 and 8 indicate the radiator temperature as a function of surface area for 1 kW radiated power at 0.95 emissivity, and specific mass as a function of thermopile mass and efficiency, electrical power is assumed converted to exhaust power at 70% efficiency, and the specific mass of the ion gun system is estimated at 1/2 kg/kW of delivered power.

INDIRECT ATOMIC AND SOLAR POWER SYSTEMS

Exclusive reliance on solar energy to produce electric power for ion guns would necessitate more massive power plants weighing perhaps 2 kg/kW. This would be unattractive. However, a radiative system might be supplemented by atomic power. Perhaps a pile power source will be developed with a sufficiently low mass in the future to make such a system practicable. A pile heating thermocouples is not likely to be a satisfactory system.

APPLICABILITY OF THE DESIGN FORMULAE

The author emphasizes that the design formulae represented by Figures 1, 2, 3, and 4 hold only for the case of optimum power/fuel mass-ratios and for specific masses that are independent of power plant size. However, for a power plant utilizing an atomic pile, the efficiency will increase with plant size, at least until some definite size is reached. The design formulae should hold fairly accurately for all forms of solar plants. In the ion gun appreciable losses must be expected to occur in the ionizing process.

FURTHER TRANSPORT CONSIDERATIONS

It is pointed out that, while short transit times are important for manned flights, longer and, consequently, more economical flights are conceivable for unmanned cargo trips. It is worthy of note that various sections of the operating plants discussed can be simulated in the laboratory and, where that is not possible, as in the case of stress-free frameworks, the problems are susceptible to mathematical analysis.

DAC COMMENTS

The treatise contains many interesting speculations. However, the nonchalance with which tenuous stress-free structures of enormous size requiring accurate alignment and delicate plumbing are treated is, in our opinion, over-optimistic. More realistic assessments of the weight of structures and machinery would tend to place all of the so seriously proposed schemes in the realm of fantasy for a long time to come.

Listings: LIA 763
A-GC 18

GJM
Dec. '54

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Astronautics Literature Review

Serial 005a

PHOTON PROPULSION

Title: PROBLEMS OF ROCKET PROPULSION AT THE 4TH INTERNATIONAL ASTRONAUTICS CONGRESS *)

Author: K. I.

Source: Interavia, Vol. VIII, No. 11, 1953, pp. 641-644

VERBATIM QUOTATION

p. 642

. . .

"Professor Dr. E. Sänger (Paris) took a step into the distant future with his lecture on photon rockets. Theoretically, it is possible to conceive of space ships which use the light pressure of a tremendously powerful light beam for propulsion. Whereas the so-called adiabatic rockets, i.e. chemical rockets, thermal and 'pure' atomic rockets, pass the released energy to the whole mass concerned in the reaction, accelerating it to speeds far below that of light, in the diabatic photon rocket the whole energy released in a nuclear reaction is radiated in the form of light energy that is not passed to the reacting substances. This gives considerably poorer momentum per unit of energy. With complete transformation of the reaction substance into radiation, momentum output, however, will be equal to that of adiabatic rockets, as both processes coincide here.

"The justification for investigating this hypothetical form of propulsion, in Professor Sänger's view, is that only the pure atomic rocket or the photon rocket can be used for obtaining extremely high cruising speeds. In the former, however, the rectification of the particles carrying the energy produced is much more difficult than in the latter. To avoid immediate melting of the mirrors used for rectification they must have an extremely high reflecting power. Through considering the transfer of energy in the elastic collision between particles requiring rectification and wall atoms, Professor Sänger came to the conclusion that the energy-carrying particles must have the smallest possible mass, i.e. that photons are particularly suitable for this purpose. Even if the energy to be produced is 100 times as great as the energy required for the same momentum in pure atomic propulsion (with heavy particles), the quantity of heat transferred to the mirror, when photons are used, can be smaller by many powers of 10, because of the substantially better reflection qualities then possible. In this way it might be possible to prevent the mirror from melting.

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*) These lectures to be published in volume form at the beginning of 1954 by the Swiss Astronautical Study Group (Postfach 37, Baden)

"However, it will be extremely difficult to make the 'nuclear lamp' required for the photon rocket. This is a device which supplies the energy released during nuclear reaction in the form of light. Materials of considerably higher transparency than today's optical glass would have to be found, as even a very small absorption of light would suffice, with the tremendous amount of energy radiated, to melt the lamp.

"Professor Sänger foresaw fantastic future possibilities, if the photon rocket is ever realized. Interplanetary speeds of several percent of the speed of light would be possible, though a space ship with this type of propulsion would have to manoeuvre extremely carefully. Its light beam, which is comparable to a hydrogen bomb explosion expanded in time and space, should never pass within several thousand kilometres of the Earth or other space ships, as it would otherwise burn everything up."

WBK
Dec. '54

Title: PROBLEMS OF ROCKET PROPULSION AT THE 4TH INTERNATIONAL ASTRONAUTICS CONGRESS *)

Author: K. I.

Source: Interavia, Vol. VIII, No. 11, 1953, pp. 641-644

VERBATIM QUOTATIONS

p. 641-642

...

"There are, however, other types of propulsion. Dr. Irene Sänger-Bredt (Paris) discussed the thermodynamics of the so-called 'thermal atomic rockets'. These permit of the utilization of the high energies of nuclear reactions, without, however, their concentration of energy. The energy released by the nuclear reaction is transmitted to a 'working gas', several times greater in quantity than the mass concerned in the reaction. Pressure and temperature of this gas can thus be selected independently of one another.

"Mrs. Sänger showed a Mollier diagram of hydrogen, allowing for dissociation and ionization, for temperature ranges of up to 10,000°K and pressures of 10^{-5} to 10^2 kg/cm^2. With the aid of this diagram the attainable exhaust velocities at various expansion ratios and combustion chamber temperatures were calculated as a function of the combustion chamber pressure. For given temperatures there are found to be maxima for the exhaust velocity attainable for various combustion chamber pressures; these correspond to the state of almost complete dissociation and ionization respectively. In the case of gases which transmit heat to the walls chiefly by radiation it would be necessary to work in the neighbourhood of these maxima, as in such cases equal temperature corresponds to equal heat transfer. As is known, heat transfer is the primary limiting factor, as it is determined by the strength of the material and by the cooling.

"Therefore the working media given preference will be the diathermal gases, which do not begin to radiate until extremely high pressure and temperature ranges are reached. Convective heat transfer will then be of decisive importance. Mrs. Sänger assumes that, throughout the temperature range investigated, convective heat transfer is determined by the product of density, enthalpy and mean gas velocity.

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*) These lectures to be published in volume form at the beginning of 1954 by the Swiss Astronautical Study Group (Postfach 37, Baden).

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This 'convection product' -- after an initial sharp rise -- remains practically constant for a given combustion chamber pressure within a wide temperature range: for example from 3,000° to 7,000°K and at 10^{-3} kg/cm^2 and from 5,000° to 10,000°K at 10 kg/cm^2, i.e. between practically completed dissociation and the first beginnings of ionization. If convective heat transfer were really dependent on the above-mentioned products, it would be constant within these ranges. For hydrogen at 10 kg/cm^2 and 10,000°K, we should still be in the range of convective product which was mastered in Germany at the beginning of the war for a gas oil/oxygen rocket with combustion chamber pressure of 50 kg/cm^2. Because of the considerably greater enthalpy at this temperature -- with the dissociation practically completed -- exhaust velocities of 16 and 20 km/sec are obtainable for hydrogen, according to Mrs. Sänger. The lower the combustion chamber pressure, the higher may be the temperature used -- the convection product remaining constant -- and the higher will be the exhaust velocity. However this does not necessarily lead to higher final rocket velocities, as the dimensions, particularly of the nozzle, increase sharply and the thrust/nozzle area ratio is very low. The requirement for high thrust per unit area -- in contradistinction to the foregoing -- entails a need for higher combustion chamber pressures (as W. W. Neat also pointed out). The two contradictory requirements have to be reconciled to produce an optimum combustion chamber pressure, depending on the use and size of the space vehicle; e.g. for a 100-tonne rocket with a mass ratio of 5 for take-off against the force of gravity, it is 32 kg/cm^2, for a similar 10-tonne rocket, on the other hand, it is only 12 kg/cm^2. For lower accelerations, the optimum value is smaller."

WBK
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NUCLEAR PROPULSION

Title: NOTE SUR L'AUTOPROPULSION AVEC SOURCE D'ÉNERGIE SÉPARÉE

Author: M. P. Blanc (Senior Naval Ordnance Engineer)

Source MÉMORIAL DE L'ARTILLERIE FRANÇAISE of the MINISTÈRE DE LA DÉFENSE NATIONALE, Paris, Imprimerie Nationale 1951, Tome 25-1 (in French). p. 103-116

DAC ABSTRACT

While in conventional chemical fuel rockets the energy source is contained in the molecules of the ejected fluids, the present note deals with the different case where, on the contrary, a limited quantity of energy is contained separately from the ejected fluid and retained within the final mass of the rocket. The energy is assumed to be transferred in a controlled manner from the (nuclear) source to an inert working fluid.

It is shown that there then exists an optimum energy expenditure rate law, such that the exhaust velocity should increase during the acceleration of the vehicle so that the absolute slip stream velocity of the exhaust gases remain constant. Thus, the power developed by the source should always be proportional to the acceleration of the vehicle.

However, if one is content to keep the relative exhaust velocity constant (which is easier to accomplish and entails but a small sacrifice) then there exists an optimum mass ratio which is near $N = 5$; (viz: $N = 2(N-1)/N$) yields $N = 4.92$, $\ln N = 1.593$).

In a numerical example, a fictitious rocket fueled by a quantity of natural Uranium m_1 (allowing 1% of it to be fissionable and completely spent under perfect control during the propulsion period) is computed to be impelled to terrestrial escape velocity if the terminal mass is 70 m_1, and hence the gross take-off weight 355 m_1, allowing an exhaust velocity of 7.5 Km/sec.

Practical considerations are not introduced.

Index Listings: LIA 750-121
A-GC 1207

W. B. Klemperer
12/1/54

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NUCLEAR PROPULSION

IONIC PROPULSION

Title: INTERPLANETARY TRAVEL BETWEEN SATELLITE ORBITS

Author: Lyman Spitzer, Jr., Chairman, Department of Astronomy,
Princeton University Observatory, Princeton, N.J.

Source: Journal American Rocket Society, vol 22, No. 2, March-April 1952, pp. 92-96

AUTHOR'S SUMMARY

"An analysis is given of the performance to be expected of a rocket powered by nuclear energy, and utilizing an electrically accelerated ion beam to achieve a gas ejection velocity of 100 km/sec without the use of very high temperatures in the propellant gases. While such a rocket would have much too low a thrust to take off from the surface of a planet, it would appear to be capable of traveling from a circular orbit about the Earth to a circular orbit about any other planet in the solar system. Gases obtained from planetary atmospheres could be used for the propellant, and the only refueling required from the Earth would be supplies for the crew and small amounts of fissionable material. Preliminary indications are that such a rocket could feasibly be constructed and operated at the present time."

Excerpt:

...

"For an interplanetary space ship, a large thrust is not required. Such a ship, traveling between circular orbits about different planets, can accelerate relatively slowly, and while the total amount of energy required is still large, the power needed may be reduced by 1/100, and instead of the 100,000 hp used in a large chemical rocket, a few thousand hp is sufficient. The present paper describes a low-thrust, low-power ship of this type, designed to travel from one planet to another, without ever landing. The several thousand hp needed is generated in a uranium or plutonium pile, converted into electrical energy, and used to accelerate a stream of ions by purely electrical means to a speed of about 100 km per sec. Different components of this ship are discussed in the following sections, with the necessary mathematical analysis given in the appendixes.

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"The ideas outlined here are probably not new; possibly the extensive literature on space flight contains some reference to a system similar to that proposed in the present paper. No search of the literature has been made. The chief purpose of this paper is not to claim priority for any ideas but to focus attention on what promises to be the most practical means for interplanetary flight in the near future."

...

"It now remains to convert the electrical power, whose generation was discussed in the preceding section, into useful work. In particular, the only way a space ship can be propelled is by ejection of a stream of gases, and the electrical power must be used for this purpose. By use of electrostatic forces to accelerate a beam of ions, very high gas velocities can be achieved without the use of very high temperatures. The production of intense ion currents has been extensively studied in the past decade, and the acceleration of a space ship by an ion beam seems to offer no particular difficulties.

"The electrical voltage to be applied depends only on the mass of the ion to be used and the velocity desired. The equations, given in Appendix 4, show that to accelerate nitrogen ions to a speed of 100 km/sec requires a potential of 730 volts. Nitrogen is indicated as a propellant, since this gas is readily obtained from the Earth's atmosphere, and the ship can therefore obtain propellant gases in its circular orbit; this avoids the necessity of bringing tons of propellant up from the Earth's surface for every trip. Since nitrogen is probably also abundant in the atmospheres of Mars and Venus and possibly other planets, propellant gases could also be obtained at various points in the solar system.

"At the relatively low voltage of 740 volts required to accelerate nitrogen ions, space-charge effects limit the total ion current that can be accelerated. Appendix 4 shows that an accelerating area of about 7 sq yd would be needed to produce an ion beam of the necessary 2000 amp and 1500 kw. This result assumes that the accelerating voltage is applied over a distance of only a millimeter. Two fine-mesh wire screens, made with wires of very small diameter, could be placed this far apart and given the requisite potential difference. Thermionic emission from the wires in the outer screen could add electrons to the beam so that the ejected gases and the ship would remain electrically neutral.

"It may be remarked that if the accelerating voltage were increased to 100,000 volts, the ion velocities would be about 1000 km per second, and a space ship could in theory attain a speed of this order after about a hundred years of acceleration. At such a speed about a thousand years would be required to reach the nearest star."

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DAC COMMENTS

The proposed ion beam propulsion is similar in concept to that advocated by Oberth.

The article does not explain how the flow of gas from a container should be admitted to the extremely shallow electrostatic acceleration chamber, which is to consist of 7 square meters of flat anode behind which at a distance of only 1 mm (.04" !) a gossamer mesh cathode screen is stretched out and held at a potential of -740 volt relative to the anode.

It is claimed that the thermionic emission from the wire screen would add electrons to the beam "so that the ship would remain electrically neutral". It is not clear why these electrons would not rather fly towards the anode and be captured there and build up a negative charge, which would have to be dissipated without creating interference.

Listings: LIA 760-2
A-GC 3

12-3-54
W. B. Klemperer

Title: NUCLEAR ENERGY FOR AIRCRAFT PROPULSION

Author: Gabriel M. Giannini

Source: Air University Quarterly Review, vol 1, #1, Spring 1947, O. 43-51

DAC ABSTRACT

Theoretically, thrust for propulsion can be derived from a continuous reaction fission pile in three ways:

(a) Electromagnetic radiation including radiant heat: thrust is virtually nil.

(b) Momentum of fission products (neutrons, alpha and beta particles): Thrust contribution is negligible, the amount of fuel required fantastic and the operation dangerous.

(c) Heat from reaction can be imparted to a working medium, such as air while flying within the atmosphere or tanked fluid such as preferably hydrogen for space flight: These are quite feasible.

While with method (c) no drastic improvement of the propulsion plant cycle over chemically fueled jet engines or rocket is expected because limitations are governed by heat resistivity of engine structure, there remains the advantage of the negligible fuel weight for airbreathers and of the high specific heat and low weight of hydrogen for a nuclear fuel rocket.

The author emphasises the magnitude of the unsolved problems attending the development of a nuclear energy rocket, such as heat dissipation, vehicle construction, launching, control, and protection. He sees possibilities, though remote in time, only for extra-atmospheric propulsion of large vehicles rather than as any substitute for conventional chemical power plants of present-day aircraft or terrestrial missiles.

DAC COMMENT

The article is very lucidly written and worthwhile.

W. B. Klemperer
12/10/54

Listings: LIA 750-4